NRL Portable Adaptive Optics for Optical Interferometry

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Introduction: Our ability to collect reliable visual or infrared imagery of exo-atmospheric objects, both astronomical and man-made, is limited by two factors. The first is the turbulence of the Earth's atmosphere: for telescopes larger than 10 to 20 cm, turbulence introduces significant wavefront distortions. The second factor that limits our ability to image ever finer details is the maximum practical size of a single telescope. The largest telescopes are currently 10 m in diameter, corresponding to a resolution limit of ~ 0.2 arc sec at visual wavelengths. One approach to overcoming the size limitation is to build an array of several smaller telescopes to synthesize an equivalent telescope of a diameter equal to their largest separation. This technique is known as interferometry. However, if the individual telescopes are larger than 10 to 20 cm, atmospheric turbulence is still a problem to be reckoned with. One way to solve this problem is to develop a system that removes the wavefront distortions in real time. Such systems are known as adaptive optical systems, or adaptive optics (AO) for short. Combining AO with interferometry will increase our ability to image finer details on fainter objects.

The NRL System: AO systems have been developed and tested at various astronomical and DoD facilities.[1] However, current AO systems are extremely complex, expensive, and heavy, and do not lend themselves to easy duplication for multitelescope systems. Within this context, we have started a program to develop and demonstrate the feasibility of a small, portable, and affordable AO system that can be easily duplicated. We have based our system on the emerging technologies of micro-electro-machined (MEM) mirrors and liquid crystal devices (LCDs). Our system is an order of magnitude smaller, cheaper, and less complex than conventional AO systems.

Figure 4 is a schematic diagram of the layout of our AO system. The main components of this system are the wavefront sensor, the reconstructor/controller system, and the corrective element.

The wavefront sensor is the component that senses the effects of the turbulence on the incoming beam of light. There are many ways of performing this task;[1] in our case, we use a so-called "Shack-Hartmann" sensor. This sensor consists of an array of lenslets that breaks the incoming beam into several sub-beams and then focuses them onto a fast-readout camera. The differential motions of the images from the sub-beams indicate the variations in wavefront tilt in each sub-beam caused by atmospheric turbulence.

The camera output goes into the reconstructor/controller computer system. The task of this component is to reconstruct the effect of the atmosphere from the camera signals, and then to send a series of signals to the corrective element to remove these effects. Since corrections are normally required at the rate of several tens to hundreds of times per second, it is critical for the controller to monitor the status of the system and ensure that the signals to the corrective element are sent in a timely fashion.

Finally, the corrective element is the component that physically removes the effects of the turbulence. Several types of corrector with different physical characteristics and capabilities are available. The MEM mirror used in our current test system is composed of a very thin metallic membrane lying on a layer of electrodes. The reconstructor/controller calculates and applies a voltage to each electrode; the resulting electrostatic force pulls the membrane inward at that point. Since, in general, the voltage for each electrode is different, the shape of the mirror is changed.

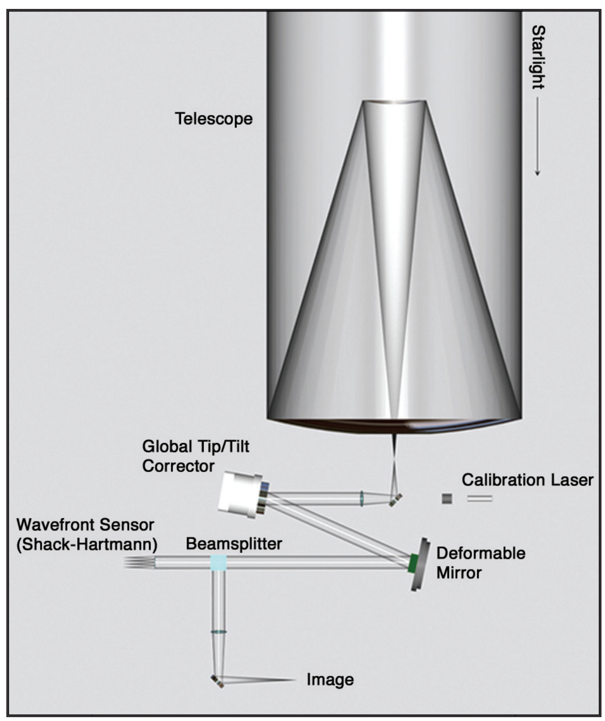

FIGURE 4
Schematic diagram of a generic adaptive optics system.

Testing: The system was tested on a 1-m telescope at the Naval Observatory Flagstaff Station (NOFS). The results of this ground-breaking experiment are reported in Refs. 2 and 3. Figure 5 shows the image of the bright star α Lyrae (Vega). The left-hand side shows the image seen by the telescope without the help of the AO system; the right-hand side shows the same stellar image with the help of the AO system. Figure 6 is a cross cut of the images in Fig. 5. The dashed line is the cross cut of the open-loop image, i.e., no AO used, and the solid line is the closed loop, i.e., AO used, cross cut.

[Sponsored by ONR]

References

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[3] S.R. Restaino, "Experimental Results from a MEM-based AO System," *S.P.I.E.* **5348**, 160-165 (2004).

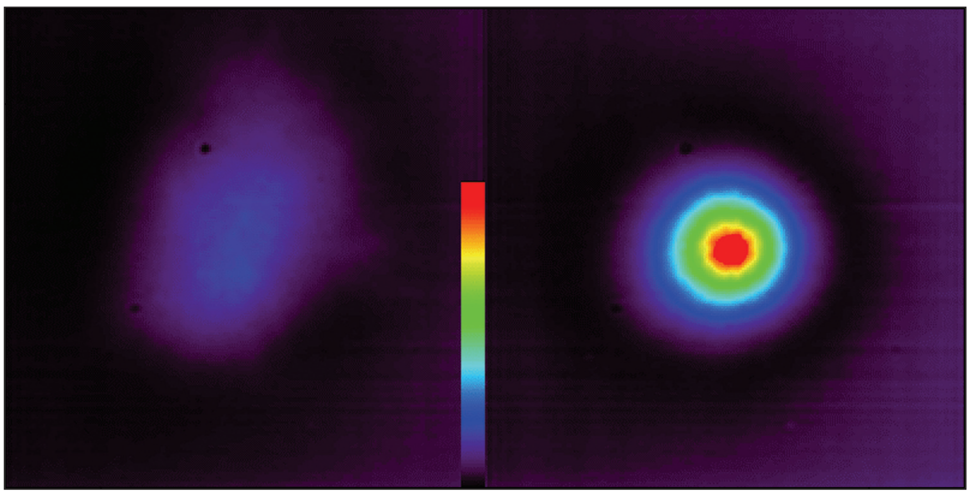

FIGURE 5
Image of the bright star alpha Lyrae (Vega). Each image is an average of 30 frames. The left side shows the open loop, i.e., no adaptive optics, and the right shows the same image with the adaptive optics system on, i.e., closed loop.

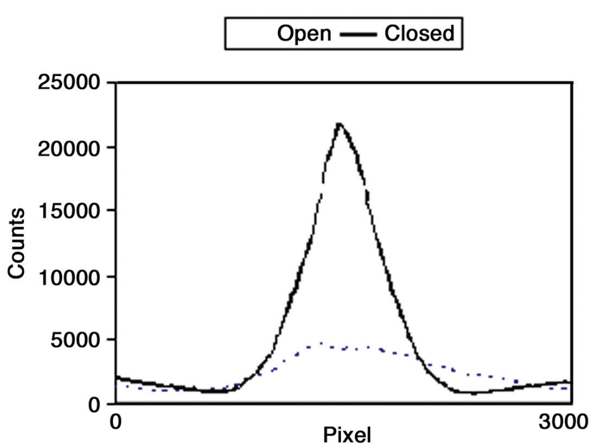

FIGURE 6
Cross cut of the two images in Fig. 5. The solid line is the cross cut of the closed loop image and the dashed line is the cross cut of the open loop image.